PARTICIPATION & TRANSFER OF LEARNING BETWEEN TERTIARY MATHEMATICS, SCIENCE, AND ENGINEERING EDUCATION

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ABSTRACT
Transfer of mathematical learning is critically important in science education and learning as mathematical knowledge and skills are applied into diverse disciplines. However, little research on transfer of tertiary mathematical learning has been conducted despite its importance. This study conducts mixed methods naturalistic inquiry to investigate transferability of mathematics from various angles using a range of research methodologies (secondary data analysis, case studies and a Delphi study) and variables within natural settings and processes of university education. The study will further extensively examine the relationship between students' educational, socio-economic, demographic and cultural backgrounds and the transferability of mathematics from first year service courses. Preliminary findings examining the maths service course undergraduate cohort show that: high socioeconomic backgrounds dominate; participation in the different levels of courses varies according to degree (engineering students take normal levels courses but science students are polarized in introductory/fundamental courses and advanced/talented programs) and gender (females tend to take introductory/fundamental courses). Later phases of research on this cohort will measure and examine the transfer of maths learning to a range of units in students' respective science degrees.

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INTRODUCTION
The central role of mathematics in modern society is uncontested. Since the twentieth century, modern societies in the developed countries, including Australia, have been transformed by the rapid development of various sciences and technologies: within the physical and life sciences and information and communication technology (Rubenstien, 2009). In addition, a provision of well-qualified scientists and engineers is essential to prosperity of societies in future (Office of the Chief Scientist, 2012). Mathematics plays a vital foundational role in all these sciences and technologies (Rubenstien, 2009) and is applied across diverse disciplines, including biology, economics, finance and medicine (CMS; BMSA-DEPS; NRC, 2013).

The interdisciplinary nature of applied mathematics is critically important as exchanges between mathematics and other disciplines lead to the advancement of both of them. Consequently mathematics education needs to consider the implications of this interdisciplinarity in terms of effective teaching and learning (CMS; BMSA-DEPS; NRC, 2013). In this study, the transfer of mathematics learning to learning in science and engineering fields is investigated.

Much of tertiary mathematics education is devoted to developing the abilities of non-mathematics specialist students in applying mathematics to their other areas of study. This ability is known as the transferability of mathematics. Demonstration of this ability is an important learning outcome in tertiary education. In Australia, the Science Learning and Teaching Academic Standards Statement sets Threshold Learning Outcomes for Science, which science graduates are expected to achieve in their degrees (Jones & Yates, 2011). The outcomes include the use of mathematics and statistics as tools for science inquiry and problem solving. Science university students are required to have abilities to deal with numerical data, algorithms and mathematical modeling (Belward, Matthews, Rylands, Coady, Adams & Simbag, 2011). More generally, according to the Australian Qualification Framework (2011), a feature of learning outcomes of any Bachelor degree is to "demonstrate the application of knowledge and skills … to adapt knowledge and skills in diverse contexts" (Australian Qualifications Framework Council, 2011, p.16). Despite its importance, little research has been conducted to investigate the transferability of mathematics in the context of higher education (Roberts, Sharma, Britton & New, 2007). Therefore, this study will address that gap by examining transfer of learning from university mathematics service units of study.

The aims of this study are (i) quantitative measurement of the transferability of undergraduate students' learning, (ii) exploring and explaining what factors are associated with the development of transferability, (iii) investigating the relationship between students' cultural, ethnic, socio-economic, demographic and educational backgrounds and transferability; and (iv) seeking experts' views on what teaching and learning factors facilitate or hinder transfer. In this paper, we present methodology and preliminary findings examining a cohort of students in maths service courses. This constitutes the first phase of the study.

METHODOLOGY

In this study a mixed methods naturalistic inquiry is conducted by employing three research strategies: secondary data analysis, case studies and Delphi study (defined and outlined in Table 1). Secondary data analysis is the main strategy used in this study. This utilises secondary data (student attainment transfer measures calculated from unit of study exam data) to investigate transferability of mathematics in terms of educational, socio-economic and cultural backgrounds of students. In addition, case studies will be embedded in secondary data analysis to examine the relationship between transferability of mathematics and prior learning, ethnic and socio-cultural backgrounds of students in greater depth. Furthermore, experts' views on teaching and learning factors enhancing transfer of mathematics are also explored through a Delphi study.

Analysis of the transferability of maths is conducted at three levels, using both quantitative and qualitative data. First, at the macro level, the relationship of students' academic performance between mathematics service courses and corresponding courses in other disciplines are investigated. The meso level is analytical as it looks at performance of transfer tasks in the exam questions and learning processes involving cognition and far transfer. Third, the micro level is examined in case studies and focuses on specific parts of questions to analyse more in-depth processes, such as metacognition.

Table 1: Summary of the methods used in this study

Three levels of analysis	Research questions	Research strategies and data collection and analysis methods
Macro	I (a). What is the cultural, ethnic, SES, demographic, educational profile of students taking mathematics service courses?	Secondary data provided by the university, e.g. age, gender, educational and ethnic information. Descriptive statistics is used for analysis.
Macro	I (b). How are attainments in mathematics service courses associated with attainments in other courses with mathematics contents?	Secondary data provided by the university, such as exam marks (mathematics and other units). Statistical analysis, such as correlation and regression, is conducted.
Meso	II. What is the measurable transfer of learning from mathematics service courses to biology, biochemistry, engineering and physics?	Secondary data provided by the university, such as exam marks. Transfer Index is used to quantitatively measure transferability of mathematics. Data will be analysed in regression analyses.
Micro	III (a). How are students' cultural, ethnic, socio-economic, demographic and educational, backgrounds associated with the transferability of mathematics?	In addition to secondary data analysis, in case studies 15 -20 semi-structured interviews are conducted. Data is analysed qualitatively, employing Grounded Theory.
Micro	III (b). What are the processes of transfer (if any) evident in students "think aloud" accounts while solving exam questions in mathematics service courses and corresponding other disciplinary courses?	In15-20 Case studies, think-aloud protocols are used in the interviews as students complete exam questions. Qualitative methods, such as content analysis, are employed.
N/A	IV. What teaching and learning factors do, mathematics and science educators believe to enhance transfer of mathematics from service courses?	In Delphi study, questionnaires are distributed by e-mail and face-to-face individual interviews are also conducted. Data is qualitatively analysed and a summary of the main ideas of experts' views on transfer Is provided.

In this paper we focus on one phase of the study addressing questions 1 and 2 and report preliminary findings on 1(a). Participants in secondary data analysis consist of multiple ‘unit of study’ cohorts studying undergraduate mathematics service courses in an urban elite, sandstone university in Australia. These students’ transfer of mathematics learning to physics, engineering, biochemistry and biology units of study will be explored.

The central concept, transferability of mathematics, will be quantitatively measured, using the *Transfer Index* developed by Roberts et al. (2007). The *Transfer Index* is calculated as the sum of transfer scores. Transfer scores are calculated by looking at matched pairs of questions testing mathematics attainment in both mathematics and other units; see Table 2 for components of composite scores. The *Transfer Index* is this sum divided by the number of relevant paired questions and multiplied by 100. In relation to using the *Transfer Index*, there are some challenges. For example, it is anticipated that in some subjects it may be difficult to find relevant questions to match up for transfer scores. If this is the case, alternative measures, using exam papers, mathematics syllabus and science exams will be developed.

Table 2: Allocation of transfer scores

Math score	1	0	1	0
Non-math score	1	1	0	0
Transfer score	2	1	0	0

RESULTS AND DISCUSSION

Preliminary findings for Q1(a) (see Table 1) provide a profile of students taking maths service units; this is summarized in Table 3. Units are categorized by the level of maths involved and this is related to the required preparation in secondary school maths. The *Introductory* unit requires no maths preparation; while *fundamental* requires at least ‘Mathematics’ (regular standard maths, previously ‘2 unit’ maths); *normal* requires ‘Mathematics’ plus ‘Extension 1’; while *advanced* maths requires ‘Extension 1 and 2’ and *talented* programs identify high achievers. Within each level similar patterns occur, for example gender ratios, international student numbers, and socio-economic background is similar in both the fundamentals units. However there are notable differences between the levels.

Gender disparities exist at all levels. Higher proportions of female students are seen in the lower level units; while in the *introductory* unit females account for 63% of the classes, in *advanced* and *talented* units less than 30% are female. This is consistent with recent reports of lower female participation in the NSW HSC mathematics (Mack & Walsh, 2013).

The proportions of international students, the majority of which are Chinese, also show some trends. Most international students attend the *normal* level maths units, with low proportions in the *introductory* and *fundamentals* courses. This may reflect better high school mathematics preparation among international cohorts (Wilson, 2013) and participation in normal maths courses is roughly consistent with the proportion of international students across this particular institution (approx. 25%). However, international students are also underrepresented in the advanced and talented programs; this is surprising given literature reporting high levels of advanced maths attainment among Chinese students (Mullis, Martin,& Foy, 2008; OECD, 2010, p131).

A total of 61 different degrees were taken by students in these courses, including 24 combined degrees and five double degrees. Somewhat surprisingly, engineering students, not science, formed the largest group in *normal* units of study. The highest proportion of science students completed the *introductory* and *fundamental* units. This is concerning as these courses are designed for students with no or minimal maths study at high school. Although math units are prerequisite for both engineering and science degrees, this data suggests that science students are polarized with high proportions in the lower level courses but also high proportions of science students in the most advanced levels, while engineering students are concentrated in the *normal* level courses. Small numbers of students from business, arts and social science degrees completed math units; almost all of these students are undertaking double degrees or combined-degrees.

Despite efforts to increase sociodemographic diversity at this university, around 64% of local students taking first year maths came from relatively high socio-economic areas; students from low SES backgrounds were unlikely to complete math service units. Across all the units between 37 and 47% of students are from the highest decile of SES classification; this means that studying maths at this university is a pursuit of the most elite sector of our society.

Table 3: Summary of background information of students in first year mathematics units

Level	Unit of Study 2012, Semester 1	Sex		International students		Degree Codes						SES Deciles		
		F	M	Non-int.	Int.	Science only	Engineer only	Science & Engineer combined	Science & Non-Engineer	Engineer & Non-Science	All Other Degrees	Low 1-3	Medium 4-7	High 8-10
Intro	**MATH1111 (n=231) Introduction to Calculus**	62.8% (145)	37.2% (86)	94.8% (219)	5.2% (12)	66.7% (154)	3.5% (8)	0% (0)	26.8% (62)	0% (0)	3.0% (7)	12.4% (27)	27.5% (60)	60.1% (131)
Fundamental	**MATH1011 (n=625) Applications to Calculus**	59.0% (369)	41.0% (256)	91.4% (571)	8.6% (54)	62.7% (392)	7.0% (44)	0.2% (1)	26.7% (167)	0.3% (2)	3.0% (19)	11.9% (68)	24.0% (137)	63.9% (365)
	MATH1015 (n=650) Biostatistics	57.8% (376)	42.2% (274)	90.8% (590)	9.2% (60)	65.2% (424)	6.6% (43)	0.2% (1)	25.5% (166)	0.3% (2)	2.2% (14)	13.6% (80)	23.1% (136)	63.3% (373)
Normal	**MATH1001 (n=1,397) Differential Calculus**	34.2% (478)	65.8% (919)	78.5% (1,097)	21.5% (300)	25.9% (362)	39.4% (551)	5.5% (77)	13.6% (190)	10.8% (151)	4.7% (66)	13.7% (150)	22.0% (241)	64.4% (706)
	MATH1002 (n=1,417) Linear Algebra	34.9% (494)	65.1% (923)	78.8% (1,117)	21.2% (300)	26.9% (381)	38.0% (539)	5.4% (76)	14.2% (201)	10.5% (149)	5.0% (71)	14.0% (156)	22.5% (251)	63.5% (709)
Advanced	**MATH1901 (n=246) Differential Calculus (Advanced)**	29.7% (73)	70.3% (173)	92.3% (227)	7.7% (19)	50.4% (124)	8.9% (22)	13.0% (32)	18.3% (45)	5.7% (14)	3.7% (9)	7.1% (16)	24.0% (54)	68.9% (155)
	MATH1902 (n=267) Linear Algebra (Advanced)	29.6% (79)	70.4% (188)	92.1% (246)	7.9% (21)	50.9% (136)	9.0% (24)	13.5% (36)	19.1% (51)	5.2% (14)	2.2% (6)	6.2% (15)	26.3% (64)	67.5% (164)
Talented	**MATH1906 (n=27) Special Studies Program A**	29.6% (8)	70.4% (19)	96.3% (26)	3.7% (1)	59.3% (16)	3.7% (1)	11.1% (3)	22.2% (6)	0% (0)	3.7% (1)	8.0% (2)	36.0% (9)	56.0% (14)
UOS Enrolment Total		2,022	2,838	4,093	767	1,989	1,232	226	888	332	193	514	952	2,617

Note: (i) Sci: Science, Eng: Engineering, Adv: Advanced (ii) Socio-Economic Indexes for Areas (SEIFA), Australia 2011, was calculated for only non-international students as no post-codes are available for international students, there is also some missing postcode data.

CONCLUSION

The study outlined here will, in several phases, provide a detailed exploration of the transfer of mathematics learning at university. This presents several challenges in operationalising the concept of *transfer* in a real-world context. Although there have been many experimental and survey studies of transfer, none to date have attempted to measure transfer within the existent assessments of university learning. By developing and refining such methodologies there is potential to examine transfer of learning further in other learning disciplines and contexts. As part of our exploration of maths transfer we have reported on the profile of students completing first year math service courses at one university. This is a neglected area of study; where the existence and value of transfer from service courses has gone unexamined but through which, it is assumed that much of the interdisciplinarity of maths is developed. The trends in gender disparity, level of course enrollments and sociodemographic profile of these students are worth reflecting on if we are to progress in promoting learning and equity in maths and science in Australian universities.

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